JACC Vol. 14, No. 7
December 1989:1666–72

Cognitive Function in Patients With Symptomatic Dilated Cardiomyopathy Before and After Cardiac Transplantation

R. RICHARD SCHALL, PHD,* RALPH J. PETRUCCI, EDD, ABPP,† SUSAN C. BROZENA, MD,† NICHOLAS C. CAVAROCCHI, MD, FACC,† MARIELL JESSUP, MD, FACC†

Philadelphia, Pennsylvania

Pre- and postoperative cognitive performance of candidates for heart transplantation was examined by means of an extensive battery of neuropsychological measures. A total of 54 patients completed the preoperative cognitive protocol, 20 of whom also completed postoperative testing. Age (<50 or ≥50 years of age) and the primary cause of cardiac deterioration (idiopathic, ischemic disease or rheumatic/congenital defects) were the major classification variables.

The main findings of this study were: 1) Preoperative neuropsychological measures revealed a high frequency of impaired performance, particularly in measures of memory, higher level processing of information and motor speed. A pattern consistent with diffuse rather than focal or lateralized cerebral deficits was observed. Significant differences were not found on the basis of the cause of cardiac disease, but some were observed for age (the older group was more impaired). 2) A comparison of pre- and postoperative cognitive scores failed to show significant cognitive improvement despite greatly improved physical health. The cause of cardiac deterioration was not differentially associated with postoperative cognitive performance, and there was equivocal evidence for age effects. These findings may have implications for the selection of transplant recipients and the timing of transplantation surgery.

(J Am Coll Cardiol 1989;14:1666–72)

The primary goals in performing cardiac transplantation in patients dying from end-stage cardiac disease are to prolong survival and return the patient to an active functional life. However, our ability to assess meaningful improvements in the quality of life for transplant recipients is limited because few objective measures have been applied to this group of patients (1). Although there are many components that should be considered in assessing the overall quality of life, cognitive functioning is a key determinant of the individual's ability to manage the demands of daily living, follow a complex medical regimen and adapt to the variety of challenges imposed by the resumption of social and occupational roles. Thus, the effect of end-stage heart disease on the cognitive status of patients awaiting transplantation and the extent to which cognitive functioning may change after transplantation could have a major impact on the long-term outcome with respect to the quality of life experienced by the transplant recipient.

The aims of this investigation were to: 1) assess the preoperative cognitive functioning of individuals with symptomatic dilated cardiomyopathy and obtain objective psychometric measures for use as a baseline; and 2) compare pre- and postoperative psychometric measures in order to investigate the effects of cardiac transplantation on cognitive function.

Methods

The neuropsychological examination procedures described in this report were part of the overall protocol approved by the Human Subjects Committee of Temple University Hospital and the Commonwealth of Pennsylvania for the establishment of a heart transplantation program (February 1984).

Study patients. Since June 1986, patients admitted to Temple University Hospital for the inpatient phase of evaluation for cardiac transplantation have also undergone a comprehensive psychological review. Formal psychological and neuropsychologic assessments were performed with all stable patients after obtaining their consent. Patients were informed that the psychological assessment was one step in

From the *Moss Rehabilitation Hospital, and †Temple University Hospital, Philadelphia, Pennsylvania.

Manuscript received March 6, 1989; revised manuscript received June 28, 1989, accepted July 6, 1989.

Address for reprints: Ralph J. Petrucci, EdD, Department of Psychiatry, Temple University Hospital, 3401 North Broad Street, Philadelphia, Pennsylvania 19140.

0735-1097/89/$3.50

the evaluation process to determine eligibility for transplantation, and that the provision of psychological services represented a recognition of the extraordinary stressors experienced by the patient and family. In addition, the testing also served to screen for significant cerebral involvement that might indicate complications unknown to the patient or referring physician. Patients were informed that the extent of the testing was the same for all patients, that confidentiality would be maintained and that postoperative testing would be conducted after transplantation. Several patients who declined participation in the psychological assessment protocol were accepted onto the transplant waiting list and subsequently received transplants. The preoperative psychologic assessments were not completed for some patients as a result of changes in clinical status (that is, illness, death or the availability and transplantation of a donor organ).

From the larger patient sample referred, 127 adult patients were assessed for eligibility for transplantation, 73 of whom subsequently received an orthotopic heart transplant. Of the patients accepted onto the transplant waiting list, 54 completed the entire battery of preoperative neuropsychological measures. Thirty of these 54 patients have undergone transplantation, 20 of whom have subsequently completed the postoperative neuropsychological battery.

Patient characteristics. The mean age of the 54 patients with a complete preoperative neuropsychological evaluation was 46 ± 11 years; there were 44 men and 10 women. All patients had New York Heart Association functional class IV symptoms of heart failure, 23 (45%) for <2 years and 31 (55%) for ≥2 years. The mean left ventricular ejection fraction was 20% (range 8 to 33), mean pulmonary capillary wedge pressure was 28 mm Hg (range 9 to 50) and mean cardiac index was 2.6 liters/min per m^2 (range 0.7 to 5.6). The cause of cardiac failure was idiopathic cardiomyopathy in 20 patients, ischemic cardiomyopathy in 25 and miscellaneous forms of dilated cardiomyopathy (from congenital defects or rheumatic disease) in 9. The mean number of years of education was 13 ± 3, with a minimum of 7 and maximum of 20.

The subsample of 20 patients with complete postoperative neuropsychological testing was not significantly different from the overall sample of 54 patients in terms of demographic and medical characteristics. The mean time from preoperative neuropsychological evaluation to transplantation was 2.8 ± 2.6 months, in 30 patients, whereas the mean time from transplantation to postoperative neuropsychological reassessment was 7.7 ± 3.6 months for the 20 patients who completed this follow-up evaluation. All patients were in functional class I at the time of follow-up testing.

Cognitive measures. The following cognitive measures are briefly described and constitute the major portion of the standard battery of testing used in our evaluation of transplant candidates:

1) Wechsler adult intelligence scale (2). This is a frequently used intelligence test that yields scores for overall intelligence quotient (IQ) (full scale IQ) as well as component scores for verbal analytic skills (verbal IQ) and visuospatial and visuomotor skills (performance IQ).

2) Wechsler memory scale (3). Two subtests of this test were utilized. The logical memory subtest consists of a verbal presentation of two different stories of paragraph length, with an immediate verbatim recall procedure after each story. The visual reproduction subtest requires an immediate graphic reproduction after a 10 s exposure to each of three figures. In addition to these short-term memory tasks, a 30 min delayed recall procedure was utilized for both verbal and visual tasks (4).

3) Halstead-Reitan neuropsychological battery (5). This battery of tests, selected for their sensitivity in differentiating between normal and brain-damaged subjects, is used in concert with other test data to measure and localize cerebral compromise. An *impairment index* is derived, which is the ratio of subtests falling within the impaired range to the total number of subtests. The impairment index can range from 0 (unimpaired) to 1.0 (severely impaired). The subtests measure language and motor skills, abstract reasoning, sensory-perceptual functioning and complex problem-solving.

Included in the Halstead-Reitan neuropsychological battery are the following subtests: The *category test* measures visual abstraction, problem-solving and memory. The *tactual performance test* involves tactile-kinesthetic, memory and spatial localization abilities. A blindfolded subject must place blocks of different shapes in the appropriate spaces on a board. Dominant, nondominant and combined hand performances are summed for a total time score. The memory score reflects the number of block shapes correctly drawn at the conclusion of the timed blindfolded trials. The localization score is the number of blocks drawn in correct spatial relation to each other. The *speech sounds perception test* measures oral comprehension and recognition through the proper identification of nonsense words. The *seashore rhythm test* measures recognition of different rhythmic patterns. The *finger oscillation test* measures the mean number of finger taps for 10 s trials of both dominant and nondominant hands. The Halstead-Reitan neuropsychological battery is among the most widely used and accepted cognitive measures, and has been the subject of studies in a wide variety of subjects (6).

Psychometric technique. The tests were administered by psychologists and psychology interns on staff at Temple University Hospital, and were reviewed for accuracy in scoring by a separate psychologist. Given the poor health and endurance of the patients assessed in this study, test sessions were time-limited to avoid excessive strain or fatigue. The testing was usually initiated while the patient

was in the hospital for transplant evaluation and continued over several outpatient visits, planned to coincide with other phases of the evaluation such as cardiac, dental or gynecologic follow-up studies.

Follow-up. The same battery of tests were again administered at least 3 months after the patient's discharge from the hospital after cardiac transplantation. The readministration of the cognitive tests was undertaken only when the patient was medically and psychologically stable and free from episodes of infection or cardiac rejection. All patients were in functional class I at the time of follow-up neuropsychological assessment.

Physiologic variables. A complete preoperative profile of cardiac functioning (ejection fraction, cardiac index and so on) was not available for many of the 54 patients with complete preoperative neuropsychological data. Because these findings were available in various combinations from different institutions (that utilized a variety measurement techniques) and assessed at different time intervals, it was not possible to meaningfully examine the variation in these physiologic variables in relation to neuropsychological performance. The length of time on cardiopulmonary bypass was examined in relation to postoperative performance on neuropsychological measures.

Statistical analyses. All data are presented as mean ± standard deviation. Chi-square analysis was utilized to determine differences in proportions of the patient sample falling within impairment ranges for the Wechsler memory scale subtests and the Halstead-Reitan neuropsychological battery measures so that the effects of age and cause of cardiac deterioration could be analyzed. Repeated measures analyses of variance were performed to determine whether there were differences in postoperative cognitive outcomes. A probability level of ≤ 0.05 was the criterion for statistical significance for all analyses.

Preoperative cognitive functioning. Table 1 details the results of the preoperative cognitive measures for the 54 patients with complete neuropsychological test batteries. Table 1 also presents the percents of patients with preoperative performances that fell within the impaired range according to normative standards. Impaired performances were frequent, especially for tasks requiring integration of complex visual (category test) and tactile-kinesthetic (tactual performance test) information. Memory measures (Wechsler memory scale) also indicated frequent impairment. Performances in the impaired range were less frequently observed for those measures sensitive to focal localized brain injury. Chi-square analyses revealed significant differences on the basis of age (<50 versus ≥50 years old) for the Halstead-Reitan impairment index, for two components of the tactual performance test (the memory and location scores) and for the logical memory portion of the Wechsler memory scale under the delayed recall procedure. In each case, the older group demonstrated a higher frequency of impaired performance. There were no significant differences in the frequency of impairment for the different etiologic categories of heart failure.

Table 1. Cognitive Function Tests in 54 Patients Awaiting Transplantation

Measures	Normative Standards	Preop Scores	% Mildly Impaired	% Moderately to Severely Impaired
Wechsler adult intelligence scale				
Full scale IQ	100 ± 15	110 ± 12	—	—
Verbal IQ	100 ± 15	112 ± 13	—	—
Performance IQ	100 ± 15	106 ± 13	—	—
Wechsler memory scale (average no. of details correctly recalled)				
Logical memory (verbal)	>12.5	8.9 ± 3	22	56
30 min delay	≥11.0	6.1 ± 3*	19	61
Visual reproduction	>10.5	8.8 ± 4	22	33
30 min delay	>9.5	7.5 ± 4	17	45
Halstead-Reitan neuropsychological battery				
Impairment index	≥0.26	0.45 ± 0.3*	35	39
Category test (no. of errors)	≤51	59 ± 30	32	24
Tactual performance test				
Total time (min)	≤15.6	17.1 ± 8	22	26
Memory (no. correct/10)	≥6	7.1 ± 2*	11	6
Location (no. correct/10)	≥5	3.5 ± 2*	34	35
Speech sounds perception test (no. errors/60)	≤7	7.5 ± 4	31	6
Seashore rhythm test (no. errors/30)	≤5	4.6 ± 4	24	9
Finger oscillation test (average taps per 10 s trial)				
Dominant hand	≥50	47 ± 9	28	28
Nondominant hand	≥44	44 ± 8	33	13

*Significant difference ($p < 0.05$) on the basis of age, with the group < 50 years of age demonstrating better performance. IQ = intelligence quotient; Preop = preoperative.

Postoperative cognitive functioning. Table 2 presents the mean values for the pre- and postoperative cognitive measures for the 20 patients who completed both neuropsychological evaluations. Statistical analyses indicated significant improvements in the following postoperative measures (irrespective of age group or the cause of cardiac failure): full scale IQ and performance IQ of the Wechsler adult intelligence scale, speech sounds perception test and finger oscillation test for both dominant and nondominant hands. However, with the exception of the finger oscillation test, the

Table 2. Cognitive Function Tests Before and After Cardiac Transplantation in 20 Patients

Measures	Preop Scores	Postop Scores	Significant Factors (time, age or cause of cardiac disease)
Wechsler adult intelligence scale			
Full scale IQ	116 ± 10	120 ± 7	Time*
Verbal IQ	117 ± 9	119 ± 8	
Performance IQ	111 ± 11	117 ± 7	Time
Wechsler memory scale (average no. of details correctly recalled)			
Logical memory (verbal)	9.4 ± 3	9.6 ± 3	
30 min delay	6.2 ± 3	7.1 ± 3	
Visual reproduction	9.3 ± 4	9.8 ± 3	
30 min delay	7.4 ± 4	9.3 ± 3	Age†
Halstead-Reitan neuropsychological battery			
Impairment index	0.34 ± 0.3	0.29 ± 0.2	Age
Category test (no. of errors)	43 ± 19	42 ± 24	
Tactual performance test			
Total time (min)	16.7 ± 8	14.9 ± 8	
Memory (no. correct/10)	7.8 ± 1	7.7 ± 2	
Location (no. correct/10)	3.9 ± 2	3.8 ± 2	
Speech sounds perception test (no. errors/60)	5.9 ± 2	4.9 ± 3	Time, age
Seashore rhythm test (no. errors/30)	4.1 ± 3	3.1 ± 1	
Finger oscillation test (average taps per 10 s trial)			
Dominant hand	48 ± 6	55 ± 9	Time
Nondominant hand	44 ± 5	50 ± 8	Time

*Time indicates a significant difference ($p < 0.05$) on the basis of preoperative (Preop) to postoperative (Postop) measurement with improved postoperative performance. †Age indicates significant difference ($p < 0.05$) on the basis of age, with the group <50 years of age demonstrating better performance.

magnitude of the improvement was not indicative of practical clinical (as opposed to statistical) significance. Moreover, the small improvements in the full scale and performance IQ scores may have been related to improvements in motor speed for timed subtests in the performance subtests of the Wechsler adult intelligence scale. Improved motor speed may merely reflect the improvement in physical health after cardiac transplantation, rather than cognitive changes.

The data indicated superior postoperative performance for patients <50 years of age in the Halstead-Reitan impairment index, speech sounds perception test and delayed recall for the logical memory portion of the Wechsler memory scale. There were no significant differences found on the basis of the cause of cardiac failure.

Stepwise linear regression analyses were performed to examine the relation of a number of factors to postoperative cognitive performance. These analyses indicated that postoperative emotional status, length of time on cardiopulmonary bypass and length of time between transplantation and postoperative assessment were not significantly correlated with postoperative cognitive performance.

Examination for sample bias. Examinations for possible bias in the patient sample were conducted by means of analyses of variance. First, the group that was assessed both pre- and postoperatively was somewhat less impaired cognitively, on average, at the time of preoperative testing than were the patients who completed the preoperative measures only. Additional analyses also suggest that the 54 patients for whom completed preoperative cognitive assessment protocols were available were less impaired cognitively than the remaining patients for whom only partially completed preoperative test batteries were available (based on comparisons with partial data obtained from the balance of the patient sample).

Discussion

Cognitive functioning before surgery. This investigation of cognitive function in patients with symptomatic dilated cardiomyopathy and congestive heart failure examined neuropsychological measures obtained from 54 patients who completed preoperative evaluation, and matched postoperative data from the 20 to 30 patients who subsequently underwent orthotopic heart transplantation. A high frequency of cognitive impairment was found on preoperative measures drawn from the Halstead-Reitan neuropsychological battery and Wechsler memory scale, both of which are sensitive to deviations from normal cortical functioning. Substantial numbers of patients performed within the moderately impaired range on these measures. This is in contrast to the generally intact performance on the Wechsler adult intelligence scale, supporting observations that this measure is less sensitive in detecting cognitive impairment (7). The profile of preoperative cognitive performance in this patient sample reflected diffuse cognitive deterioration, rather than focal cerebral impairment. The neuropsychological results indicated that the most frequent deficits occurred in the areas of memory and complex problem-solving.

Although studies of cognitive function have not been performed in patients in end-stage cardiac disease, it is known that significant preoperative cognitive deficits exist in other groups of patients with serious cardiac disease (8–13), as established by a variety of psychological measures. Indeed, preoperative physiologic findings (such as the electroencephalographic record) have also been shown (14) to be abnormal in many patients awaiting cardiac surgery. The cognitive deficits observed most frequently involved memory and complex integrative mental operations. Parallels

exist to similar psychometric investigations (15–17) of individuals suffering from chronic hypoxemia, who may appear unimpaired cognitively until challenged by tasks that go beyond the demands of established routines (17). A similar observation (18) has been made concerning patients with severe cardiac disease.

Cognitive functioning after surgery. It was expected that substantial gains in cognitive function would be observed at the postoperative assessment given the much improved health and more adequate tissue perfusion of the transplant recipients. However, the expected improvements were not demonstrated. Although many postoperative scores changed in the direction of improvement in performance, the magnitude of change was generally below levels that could be regarded as practically significant. The modest gains may have been the result of increased physical energy and motor speed, as well as regression effects from the more extreme levels of preoperative impairment. A case by case inspection and comparison of pre- and postoperative cognitive performance failed to reveal consistent patterns of improvements or declines in individual patients, which might have been obscured by examining the mean values of the total study group.

A number of studies have addressed the question of whether cognitive status improves or declines after surgery in which cardiopulmonary bypass procedures were utilized. With rare exceptions (8,13,19), very few studies have used comprehensive assessment batteries. Declines in postoperative cognitive performance have been noted (20,21), but the postoperative assessments occurred within 1 week of the surgery. Other studies (13,19,22–29) that have used longer intervals for reassessment (ranging from 2 months to 5 years) have reported general improvement, with early postoperative results giving way to subsequent improvement (29). It is possible that a longer delay in postoperative reassessment (longer than the mean of 7.7 months for our patient sample) would have revealed further improvement in cognitive function. However, care was taken to obtain postoperative data only from those individuals who were functioning at a healthy level (functional class I), had recovered from operative trauma and were free from episodes of cardiac rejection and infection at the time of reassessment. Regression analyses failed to demonstrate an influence of the relative length of time between transplantation and reassessment on the postoperative cognitive measures (which ranged from 3 to 15 months). Nonetheless, additional follow-up assessments are planned at approximately yearly intervals to further address the question of course of recovery and the relative stability of cognitive functioning. The impact of the ongoing immunosuppressive regimen will also be examined.

Caution has been advised in the interpretation of overall results because subgroups of patients who appeared to have experienced early postoperative neurologic complications had worse outcomes on follow-up examination (23,24,26,28, 29). The incidence of transient postoperative delirium (in the absence of major medical complications) and overt central nervous system disorders after cardiac transplantation was rare (<5%) for our patient sample and did not permit further analysis.

The documentation of cognitive function after cardiac surgery, especially surgery requiring cardiopulmonary bypass, has generally supported the notion that the increasing sophistication of bypass techniques has led to a reduced risk for cerebral deficits after surgery (30), with decreased effects of length of time on bypass. This was the case for the initial postoperative sample reported here because time on cardiopulmonary bypass was not shown to be significantly related to postoperative cognitive performance. From this standpoint, the failure to find significant changes in postoperative cognitive functioning represents a positive finding in light of the risks that had been associated with bypass procedures in the past (10,23–25).

Influence of age and cause of cardiac deterioration. There were no significant differences in pre- or postoperative cognitive performance according to different causes of cardiac failure and no interactions noted between age and etiology. The previously cited studies of cognitive function in relation to cardiac disease and surgery did not present analyses on the basis of etiologic groups. Conclusions drawn on the basis of single diagnostic groups or the grouping together of heterogeneous diagnoses are difficult to evaluate. In the current sample, there was a small number of patients presenting with rheumatic disease and congenital defects, and differences on the basis of etiology require further examination in the future.

Younger patients (<50 years) tended to perform better on some pre- and postoperative measures, but this finding was not consistent across measures. Moreover, there has been debate concerning the applicability of identical cut-off scores for older individuals for some of the neuropsychological measures (31,32), although striking differences were found for age samples that were substantially older than the mean age (55 ± 3 years) for the "older" group in this study. Thus, the instances of superior performance by the younger group of patients were not surprising, but alternative normative standards that would permit a more rigorous analysis of such differences have not been established.

Influence of sample bias. Examinations for possible bias in the patient sample yielded important information. There were indications that the patient sample completing both pre- and postoperative assessments exhibited less cognitive impairment preoperatively than the sample that completed only the preoperative assessment. Conclusions about postoperative outcome must be tempered by the observation that there may have been a "ceiling effect" in which the more cognitively impaired patients, the ones who may have had more range for postoperative improvement, were not assessed.

Additionally, data analyses for complete and partial preoperative cognitive assessment protocols revealed that those

patients who did not complete the preoperative test battery were likely to have been more impaired cognitively than the group for whom complete preoperative data were available. Failure to complete the protocol was frequently associated with illness, death or heart transplantation before testing could be completed. Thus, the results addressing the frequency and severity of preoperative impairment may actually underestimate the extent of cognitive dysfunction in the general group of patients with end-stage cardiomyopathy.

Clinical implications. Given the high proportion of patients with preoperative cognitive deficits, the failure to find significant improvement postoperatively raises several troubling questions. In large measure, priority for heart transplantation is established by the extent of physical deterioration and the imminence of death. Although these imperatives may provide an ethically clear component in the consideration of recipient selection, it may be that some measure of irreversible cognitive decline has occurred by that point. Should this be the case, the level of cognitive functioning may have a place in considering the timing of transplantation, as well as guiding expectations for level of cognitive function and overall adjustment postoperatively. However, until the results of this study are substantiated by larger patient samples and independent investigators, it would not be reasonable to exclude patients from cardiac transplantation on the basis of cognitive function alone. Despite these issues, further investigation of the course of changes in cognitive function throughout differing levels of severity of cardiac disease (in conjunction with other physiologic variables) and across time would be valuable.

Considering the evidence of impairment in cognition both before and after cardiac transplantation, these factors should also be considered when dealing with patients who exhibit difficulties with adjustment and coping after transplantation. What may at first appear to be emotional or characterologic maladjustment, or both, or assumed to be effects of the medication regimen may mask complications of subtle cognitive difficulties not evident to the patient, family or medical support team.

The impact of cognitive status and other factors on the subsequent adjustment, quality of life and life satisfaction for transplant recipients and their families is an important question that is not addressed in this study, but is a focus of the ongoing investigation at Temple University Hospital. In addition, the longer-term effects of the immunosuppressive regimen on cognitive functioning, life quality and adjustment need to be examined.

We thank Alan Sockloff, PhD of Temple University for his contributions to the statistical analyses employed in this study, Kevin Riley, PhD and Susan Beebe, PhD for their assistance in clinical management and data collection and Anne Carter, PhD and Margaret Keenan, MA in the collection of data.

References

1. Norvell N, Conti CR, Hecker J. Heart transplantation candidates: psychological evaluation. Prim Cardiol 1987;13:20–8.
2. Wechsler D. Manual for the Wechsler Adult Intelligence Scale. New York: The Psychological Corporation, 1955.
3. Wechsler D. A standardized memory scale for clinical use. J Psychol 1945;19:87–95.
4. Russell EW. A multiple scoring method for the assessment of complex memory functions. J Consult Clin Psychol 1975;43:800–9.
5. Reitan RM. Investigation of the validity of Halstead's measure of biological intelligence. Arch Neurol Psych 1955;73:28–35.
6. Strub RL, Black FW. Neurobehavioral Disorders: A Clinical Approach. Philadelphia: F.A. Davis, 1988:78.
7. Russell EW. Neuropsychological interpretation of the WAIS. Neuropsychology 1987;1:2–6.
8. Priest WS, Zaks MS, Yacorzynski GK, Boshes B. The neurologic, psychiatric, and psychologic aspects of cardiac surgery. Med Clin North Am 1957;41:155–69.
9. Kezdi P, Zaks MS, Costello HJ, Boshes B. The impact of chronic circulatory impairment on functioning of the central nervous system. Ann Intern Med 1965;62:67–79.
10. Lee WH, Brady MP, Rowe JM, Miller WC. Effects of extracorporeal circulation upon behavior, personality, and brain function. II. Hemodynamic, metabolic, and psychometric correlations. Ann Surg 1971;173: 1013–23.
11. Kimball CP. The experience of open heart surgery. III. Toward a definition and understanding of postcardiotomy delirium. Arch Gen Psychiatry 1972;27:57–63.
12. Willner AE, Rabiner CJ, Wisoff BG, et al. Analogy tests and psychopathology at follow-up after open heart surgery. Biol Psychiatry 1976; 11:687–96.
13. Sy MJ. Neuropsychological changes after open-heart surgery. (Doctoral dissertation, Fordham University, 1981). Ann Arbor, MI: University Microfilms International, 1981:52–56.
14. Sotaniemi KA. Brain damage and neurological outcome after open-heart surgery. J Neurol Neurosurg Psychiatry 1980;43:127–35.
15. Grant I, Heaton RK, McSweeney AJ, Adams KM, Timms RM. Brain dysfunction in COPD. Chest 1980;77(suppl 2):308–9.
16. Prigatano GP, Parsons O, Wright E, Levin DC, Hawryluk G. Neuropsychological test performance in mildly hypoxemic patients with chronic obstructive pulmonary disease. J Consult Clin Psychol 1983;51:108–16.
17. Greenberg GD, Ryan JJ, Bourlier PF. Psychological and neuropsychological aspects of COPD. Psychosomatics 1985;26:29–33.
18. Kornfeld DS, Zimberg S, Malm JR. Psychiatric complications of open heart surgery. N Engl J Med 1965;273:287–92.
19. Juolasmaa A, Outakoski J, Hirvenoja R, Tienari P, Sotaniemi K, Takkunen R. Effect of open heart surgery on intellectual performance. J Clin Neuropsychol 1981;3:181–97.
20. Shealy AE, Walker DR. Minnesota multiphasic personality inventory prediction of intellectual changes following cardiac surgery. J Nerv Ment Dis 1978;166:263–7.
21. Fish KJ, Helms K, Sarnquist FH, Tinklenberg J, Miller DC. Neuropsychological dysfunction after coronary artery surgery. Anesthesiology 1982;37:55.
22. Aberg T, Kihlgren M. Effect of open-heart surgery on intellectual function. Scand J Thorac Cardiovasc Surg 1974;15(suppl):1–67.
23. Aberg T, Kihlgren M. Cerebral protection during open-heart surgery. Thorax 1977;32:525–33.
24. Frank KA, Heller SS, Kornfeld DS, Malm JR. Long-term effects of open heart surgery on intellectual function. J Thorac Cardiovasc Surg 1972; 64:811–5.

25. Willner AE, Rabiner CJ, Wisoff BG, Hartstein M, Struve FA, Klein DF. Analogical reasoning and postoperative outcome. Arch Gen Psychiatry 1976;33:255–9.

26. Willner AE, Rabiner CJ. Psychopathology and cognitive dysfunction five years after open heart surgery. Compr Psychiatry 1979;20:409–18.

27. Savageau JA, Stanton B, Jenkins CD, Klein MD. Neuropsychological dysfunction following elective cardiac operation. I. Early assessment. J Thorac Cardiovasc Surg 1982;84:585–94.

28. Savageau JA, Stanton B, Jenkins CD, Frater RWM. Neuropsychological dysfunction following open heart surgery. II. A six-month reassessment. J Thorac Cardiovasc Surg 1982;84:595–600.

29. Sotaniemi KA, Mononen H, Hokkanen TE. Long-term cerebral outcome after open heart surgery: a five-year neuropsychological followup study. Stroke 1986;17:410–6.

30. Aberg T, Kihlgren M, Jonsson L, et al. Improved cerebral protection during open-heart surgery: a psychometric investigation on 339 patients. In: Becker R, Katz J, Polonius MJ, Speidel H, eds. Psychopathological and Neurological Dysfunctions Following Open-Heart Surgery. New York: Springer-Verlag, 1982:343–51.

31. Bak JS, Greene RL. Changes in neuropsychological functioning in an aging population. J Consult Clin Psychol 1980;48:395–9.

32. Bornstein RA. Classification rates obtained with "standard" cut-off scores on selected neuropsychological measures. J Clin Exp Neuropsych 1986;8:413–20.